(12) UK Patent Application (19) GB (11) 2 265 059 (13) A

(43) Date of A publication 15.09.1993

(21) Application No 9204650.7

(22) Date of filing 04.03.1992

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(51) INT CL[5]
H04B 10/18

(52) UK CL (Edition L)
H4B BK18

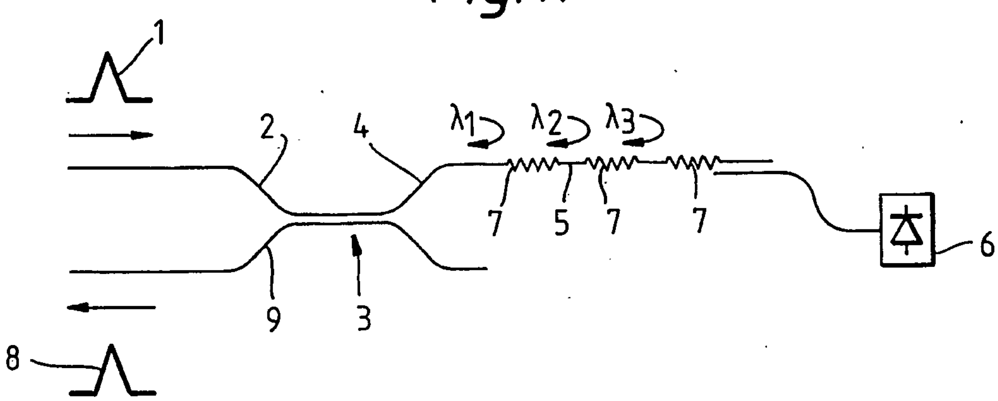
(56) Documents cited
GB 2161612 A US 5048909 A

(58) Field of search
UK CL (Edition K) H4B BK16 BK16D BK18
INT CL[5] H04B

(54) **Optical regenerators**

(57) An optical regenerator is comprised by an amplifying optical fibre (5) and directional coupler means (3). An input pulse (1) is reflected, by a respective grating (7) written in the optical fibre, in dependence on the spectral content of the pulse (1). The output pulse (8) is thus reshaped (amplified) and narrowed spectrally. The gratings have different spacings, at least in use of the regenerator, so that output pulses with predetermined characteristics can be achieved.

Fig. 1.



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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Fig. 1.

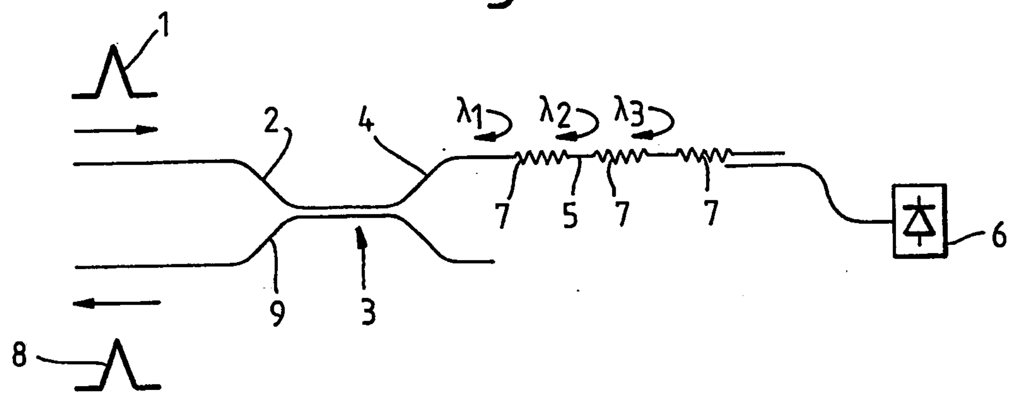


Fig. 2.

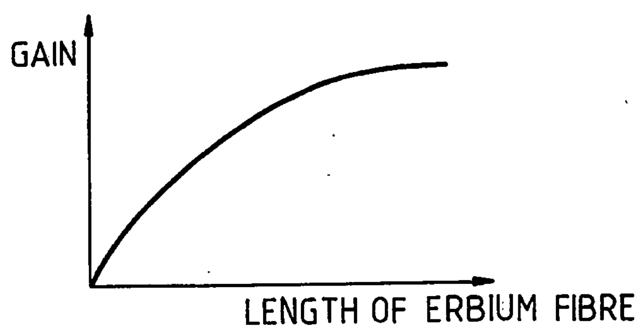
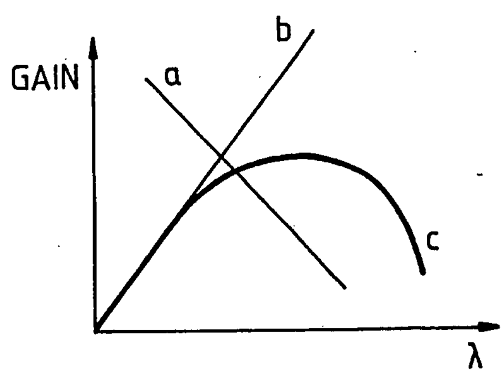


Fig. 3.



OPTICAL REGENERATORS

This invention relates to optical regenerators, that is to say optical means for both reshaping (amplifying) and narrowing spectrally optical pulses.

Optical amplifiers such as erbium doped fibre amplifiers are finding increasing application. However, they simply provide amplification whereas, for example, for long distance telecommunications, such as submarine, applications, spectral narrowing is also required.

According to the present invention there is provided an optical regenerator comprising an amplifying optical waveguide and directional coupler means serving to couple an input optical pulse to said waveguide and to couple a corresponding output optical pulse therefrom, the optical waveguide having a number of gratings along its length, a respective one of which in dependence on the spectral content of the input pulse serves to reflect the input optical pulse back to the coupler means in use of the regenerator, the amplifying optical waveguide thereby serving to amplify the input optical pulse differentially, and the regenerator thereby providing output pulses with predetermined characteristics.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which

Fig. 1 illustrates, schematically, an embodiment of optical regenerator according to the present invention;

Fig. 2 illustrates the variation of gain with length for erbium fibre, and

Fig. 3 illustrates the variation of gain with wavelength for erbium fibre in which gratings have been written.

Referring firstly to Fig. 1, it is assumed that an incoming pulse 1 to be regenerated is chirped, that is it has a spectral chirp (varies in wavelength) due to the dispersion of the fibre along which it is transmitted. As illustrated, this incoming pulse 1 is applied to one arm 2 of a 3dB optical fibre coupler 3. To another arm 4 of the coupler 3 is connected a length of erbium fibre 5. The erbium fibre 5 is pumped by a pump 6 outputting at a suitable wavelength whereby to achieve amplification of an input pulse such as 1. Gratings 7, of different spacings as illustrated, are written in the erbium fibre 5. Hence the gratings serve to reflect different wavelength components, as illustrated, wavelength λ_1, is reflected by the first grating encountered by an input pulse; wavelength λ_2 is reflected by the second grating encountered by an input pulse and wavelength λ_3 is reflected by the third grating encountered by the input pulse.

As mentioned, the erbium fibre is pumped by pump 6, this being reverse pumping as the pump signal is directed in the opposite direction to the propagation direction of the input pulse. Gain is achieved in the fibre as a function of length therealong, as illustrated in Fig. 2. This highest gain being achieved in the erbium fibre closest to the pump. Hence a different amount of gain is applied to each reflected spectral component (different wavelength λ_1,λ_2,λ_3) i.e. there is differential gain and this can be tailored in order to reshape the pulse spectrally as desired, by adjusting the selected grating spacings. Any pulse shaping characteristic may be selected. Fig. 3 shows variation of gain with wavelength for the wavelength increasing (a) and decreasing (b) (these being determined by the gratings) and also wavelength

peaking (c). The reshaped output pulse 8 is output from arm 9 of coupler 3. The optical regenerator of Fig. 1 thus narrows (spectrally) and reshapes (amplifies) an input pulse. This is in comparison with our previous proposal GB 2161612B (R E Epworth 27) which achieves pulse narrowing alone in a chromatic dispersion equaliser comprising a chirped Bragg reflector permanently written in an optical fibre coupled to a transmission fibre by directional coupler means which may comprise, for example a 3dB optical fibre coupler as mentioned above, or a optical circulator which does not involve the 3dB loss of the optical fibre coupler. Since the regenerator of the present invention involves gain, the 3dB loss inherent with the fibre coupler is of little consequence, i.e. only 3dB gain is required to overcome the loss at the coupler and this can easily be provided by the erbium fibre. As illustrated in Fig. 3, curve (a) indicates that the gain decreases with increasing wavelength and the arrangement can be tailored as required. The variations in the gratings do not necessarily have to involve a linear increase. The gratings spacings are chosen to achieve the required shaping and could for example involve the first and third gratings of Fig. 1 having respective spacings which are both different but are also both greater or smaller than the second grating.

The chirped Bragg reflector of our previous proposal comprised a conventional single mode communications fibre in which the grating can be permanently written by a technique first proposed by K O Hill et al in 1978, "Photosensitivity in optical fibre wavelengths: application to reflection fibre fabrication: Appl. Phys. Lett. 32,647(1978), although this is not the only method which can be employed. The Hill method involves axially written gratings achieved due to photorefractive effects. It is the photosensitivity of the conventional fibre which provides the photorefraction, and the photosensitivity effect in conventional fibre which has been most studied is believed to be due to germania defects in the germania doped silica. Another method which can be employed for producing photorefractive (phase)

gratings is that of traversly written holographic gratings. Surface relief gratings can also be produced such as by the method described in GB 2189901B (K C Byron 24) involving plasmon/polariton excitation, or by laser micro-machining. An advantage of the latter method is that long gratings may be written and chirped and phase-jumped features readily incorporated into the gratings. The basic Hill method for grating writing may be used to write a series of differently spaced gratings in a single length of fibre if, for example, the fibre has a gradient of conditions applied to it whilst the grating is being written, or if such a gradient of conditions is subsequently applied by stretching the fibre, as discussed in GB 2161612B. Alternatively differently spaced gratings can be written in different lengths of fibres which are subsequently spliced together.

Whereas Fig. 1 and the above description relate to a number of gratings each having different spacings provided in an erbium fibre, an alternative is to provide a number of identical gratings (identical spacing) along a fibre and provide each of them with a respective overlay of a non-linear material. When the non-linear overlay of any such grating is optically pumped, the refractive index changes and hence the associated grating spacing changes. Hence the result produced by such an arrangement can be tailored to produce any required pulse reshaping as well as amplification.

The Hill or other photorefractive based methods of grating writing whilst previously only applied to conventional communications optical fibre (germania doped silica) are not adversely affected by the presence of erbium since the latter does not involve a photorefractive effect. When gratings are so written, the erbium is not involved; it is effectively not present. The erbium is required in the present instance solely for providing gain i.e. an amplifying medium. Other rare earths, such as europium, could be added to the erbium fibre since europium does exhibit a photorefractive effect and this is required for grating writing by the Hill-based method. Basically, however, erbium doped

GeO_2/SiO_2 fibre will provide good gratings in view of the germania. The additional presence of europium, for example, may provide enhanced grating writing as well as enhanced gain.

CLAIMS

1. An optical regenerator comprising an amplifying optical waveguide and directional coupler means serving to couple an input optical pulse to said waveguide and to couple a corresponding output optical pulse therefrom, the optical waveguide having a number of gratings along its length, a respective one of which in dependence on the spectral content of the input pulse serves to reflect the input optical pulse back to the coupler means in use of the regenerator, the amplifying optical waveguide thereby serving to amplify the input optical pulse differentially, and the regenerator thereby providing output pulses with predetermined characteristics.

2. An optical regenerator as claimed in claim 1, wherein the amplifying optical wave guide is a length of amplifying optical fibre one end of which is coupled to said directional coupler means.

3. An optical regenerator as claimed in claim 2, wherein an optical pump source is coupled to the other end of the amplifying optical fibre.

4. An optical regenerator as claimed in claim 2 or claim 3 wherein the fibre is an erbium doped amplifying optical fibre.

5. An optical regenerator as claimed in any one of claims 2 to 4 wherein the directional coupler means is an optical fibre coupler.

6. An optical regenerator as claimed in any one of claims 2 to 5 and wherein the gratings were permanently written in the optical fibre.

7. An optical regenerator as claimed in any one of claims 1 to 6, wherein the gratings have the same spacings when the regenerator is not in use and wherein means are provided whereby in use of the regenerator the spacing of one or more of the gratings is changed to provide the predetermined characteristics.

9. An optical regenerator as claimed in claim 8 wherein the gratings are permanently written in the optical fibre and are each provided with a respective non-linear overlay, and including optical pump means for the overlays whereby in use the pump means for the overlay of a predetermined grating is actuated and the spacing of the predetermined grating changed.

10. An optical regenerator as claimed in claim 2 or claim 3 wherein the fibre is an erbium doped amplifying $Ge0_2/Si0_2$ optical fibre.

11. An optical regenerator substantially as herein described with reference to as illustrated in the accompanying drawings.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

Application number

9204650.7

Relevant Technical fields

(i) UK Cl (Edition K) H4B:BK16; BK16D; BK18

(ii) Int CL (Edition 5) H04B

Search Examiner

ALAN STRAYTON

Databases (see over)

(i) UK Patent Office

(ii)

Date of Search

18 JUNE 1992

Documents considered relevant following a search in respect of claims ALL

Category (see over)	Identity of document and relevant passages		Relevant to claim(s)
A	GB 2161612 A	page 2, line 53 - page 3, line 10	
A	US 5048909	Figure 6 and column 5, line 33 - column 6, line 12	

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

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